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GEOPHYSICAL INVESTIGATION OF THE AREA AROUND WARM SPRINGS STATE HOSPITAL TO DELINEATE POSSIBLE AREAS FOR DISCOVERY OF GEOTHERMAL RESOURCES

Prepared for

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GEOPHYSICAL INVESTIGATION OF THE AREA AROUND WARM SPRINGS STATE HOSPITAL TO DELINEATE POSSIBLE AREAS FOR DISCOVERY OF GEOTHERMAL RESOURCES

Prepared by

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PROJECT IMPLEMENTATION

1. Project Planning

Previous geophysical surveys conducted near potential geothermal areas of Southwestern Montana by the geophysical engineering department of Montana Tech had indicated that certain geophysical anomalies might be expected to be associated with potential geothermal sites. Based upon this previous experience and a literature review of (a) other geophysical surveys in Montana's possible geothermal areas, and (b) the geology of the Warm Springs area; we determined that three types of geophysical surveys should be attempted in the target area. The surveys were to include gravity, magnetic and resistivity methods. Cultural noise in the target area soon eliminated the magnetic method from serious consideration, and so plans were made for gravity and resistivity surveys.

a. Gravity survey - The extent and expression of any gravitational anomaly associated with the warm springs was unknown at the beginning of the project, but based upon previous experience gained in other areas, we determined that gravitational anomalies might be small in magnitude and lateral extent. Therefore, they might be found only by a very precise survey with very closely spaced data points. For this type of gravity survey to be successful it is necessary to establish the positions of the survey stations much more precisely than is ordinarily required. The first requirement of the survey was then recognized to be the precise location [both vertical and horizontal] of each survey station. The network of stations, located in more or less concentric rings around the surface expression of the warm springs, was positioned such that the station spacing was approximately one station every 300 ft. The relative elevations of each station were determined within ±0.1 ft. by the leveling methods of plane surveying. Horizontal positions were determined by the stadia method of plane surveying. All survey networks were closed loops, and were adjusted using standard surveying procedures.

After the elevations and locations of the survey stations had been established, a Worden gravimeter was used to measure the relative vertical components of attraction at each of the stations. The instrument used was an educator model Ser. 181 Mod. 130 with a dial constant of 0.4017(8) mgals/dial division. By use of a vernier located on the dial, it is possible to obtain readings to an accuracy of ±0.1 dial divisions. The accuracy of the survey is therefore established as ±0.1 dial div. x 0.4017(8) mgal/dial div., or approximately ±0.04 mgal by the instrument used. The elevation control, ±0.1 ft., allows reading corrections to ±0.1 ft. x 0.09 mgal/ft., or approximately ±0.009 mgal. Position determinations of the stations are also well within tolerance because corrections for North/south location variations at the latitude of Warms Springs are approximately 0.00025 mgal/ft. so that locations with uncertainties in North/south positions of 40 ft. will be associated with gravitational uncertainties of approximately ±0.008 mgals. From the above calculations, it is obvious that the limiting factor of the survey is the mechanical limitation imposed by the gravimeter itself.

b. Resistivity survey - Immediately preceding the initiation of this geophysical survey program the geophysical engineering department acquired a Newmont I.P. 25 W system. We therefore decided to use this system to check the I.P. response near the warm springs, and also to use the system to perform normal resistivity surveys in the target area. Initial measurements showed no apparent I.P. response so that no emphasis was placed on obtaining this type of data. The power limitations imposed by the 25 W system, and the resistivities encountered in the target area, established the survey extent.

Resistivity profiles were measured throughout the target area so that regions of low resistivity might be identified. The plan evolved such that the results of the profiling would be contoured, and then resistivity soundings would be made to obtain more detailed information at selected sites. Electrode spacings of 50 meters were used so that local pertabations might be minimized. The consistancy of the results indicated that this is a reasonable assumption, and certain regions within the target area showed lower resistivities than others such that a consistant pattern emerged.

Resistivity soundings using Wenner electrode configurations were made at 6 locations. The "a" spacings for the electrodes ranged from 1 meter to 100 meters. These soundings varified the existance of relatively low resistivity material to the maximum extent of the surveys.

Field data were obtained during the late summer and early fall months of 1978. This initial data was plotted, and indications of areas requiring further data were obtained. When the additional data had been obtained, the field portion of the survey was considered to be complete.

c. Computer applications - A modification to the computer facilities of the campus resulted in unexpected benefits to the project. From the outset, we had decided that computer assisted interpretation of the data was a necessity, and that existing programs could be used for this purpose. With the computer modifications which occurred, problems developed when the data were entered into existing programs. Although the problems were more annoying than serious, they provided the impetus required to develop a better set of programs. As a direct result of the Warm Springs project, we have developed a set of interactive graphics programs for the calculation of gravitational anomalies due to arbitrarily polygonal shaped 2-dimensional mass distributions. The programs were initially developed by Dr. David Fleming, who was previously with the geophysical engineering department of Montana Tech. The increased computer graphics capabilities developed on this project have already been utilized by other campus departments and have proved to be of value to the campus as a whole.

2. Field Procedures and Data Reduction

The locations of gravity survey points were located by the methods of plane surveying. Relative elevations were established to ±0.1 ft., and horizontal positions were established to ±10 ft. All points are located with respect to BM 4819 physically located near the entrance to the Warm Springs Hospital area. The bench mark is in the lawn, across from the store at the entrance roadway.

At each gravity station the worden gravimeter was set and leveled. A set of readings were taken at each station so that the operator had confidence in the final results. The ordinary variations at each station were less than ±0.2 dial divisions, and when averaged yielded best estimates assumed to be ±0.1 dial division. This is equivalent to approximately ±0.04 mgal.

All stations were referenced to a base, or reference, station conveniently located for the survey. Station #5 was used for the reference, and when a set of readings were taken, #5 was measured before and after the set, so that corrections for instrumental drift could be made. The usual time for returning to the base was less than 2 hours, but never exceeded three hours. Linear drift was assumed between reference station readings.

Elevation corrections were made to the data using combined free air and Bouquer corrections based on a datum elevation of 4800 ft. A Bouquer density of 2.67 gm/cc was used. Latitude corrections were also made. Terrain corrections were not made.

Contoured maps of the corrected data were made. Using well-known methods of data analysis, regional variations were removed from the gravity data. The regional is assumed to be due to the large scale features of the Deer Lodge Valley. Once the regional is removed, the resulting contour map is a reflection of the local mass distributions near Warm Springs. Interpretation of the contour maps is facilitated by use of cross-sections cut at appropriate places through the region. Two of these cross-sections have been analyzed in detail.

3. Project Results

A professional paper prepared by Halvorson and Wideman describes the results of the project and is included here as Appendix A in lieu of sections (3), (4) and (5) of the final reports on technical projects normally required by DNRC.

CONCLUSIONS AND RECOMMENDATIONS

Based upon experience gained by the Warm Springs survey and surveys previously conducted at Silver Star, Pipestone and Ennis, we conclude that geothermal areas are individuals and as such require individualist approaches for resource evaluation. No particular geophysical method is appropriate for every geothermal system. For the Warms Springs State Hospital area the gravity and resistivity surveys did identify anomalous areas associated with the warm springs, and therefore, these geophysical methods were appropriate for this project.

APPENDIX A

A GEOPHYSICAL INVESTIGATION OF THE WARM SPRINGS MONTANA AREA

by

J. W. Halvorson

and

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Boulder batholith and the Lowland Creek Volcanics form more gentle topography to the east. The Warm Springs State Hospital is approximately 25 miles from Butte by Interstate Highway 90.

PREVIOUS WORK

The geology and ground water resources of the Deer Lodge Valley are discussed in U.S. Geological Survey Water Supply Paper 1862. Included in the paper is a residual gravity map of the Deer Lodge Valley. Water data from the Warm Springs system and other southwestern Montana thermal springs is given in the U.S. Geological Survey Open File Report 78-438. Montana Bureau of Mines and Geology Special Publication 22 is a geological map of a portion of the Flint Creek Range west of the study area. U.S. Geological Survey Geophysical Publication 538 is an aeromagnetic map that includes the Deer Lodge Valley.

GEOLOGY

The Anaconda and Flint Creek Ranges are composed of Precambrian through Cretaceous sediments and metasediments with numerous igneous intrusives. Three periods of glaciation have occurred in the Flint Creek Range and deposited moraine and outwash material in the Deer Lodge Valley (Mutch, 1960).

Cretaceous quartz monzonite of the Boulder batholith and the Eocene tuffs and lava flows of the Lowland Creek volcanics outcrop a short distance east of the study area.

Valley formation probably began in the early Tertiary, before the Eocene deposition of the Lowland Creek volcanics (Konizeski, 1968). Fault scarps along the western side of the valley indicate relatively recent movement however no surface evidence for faulting along the

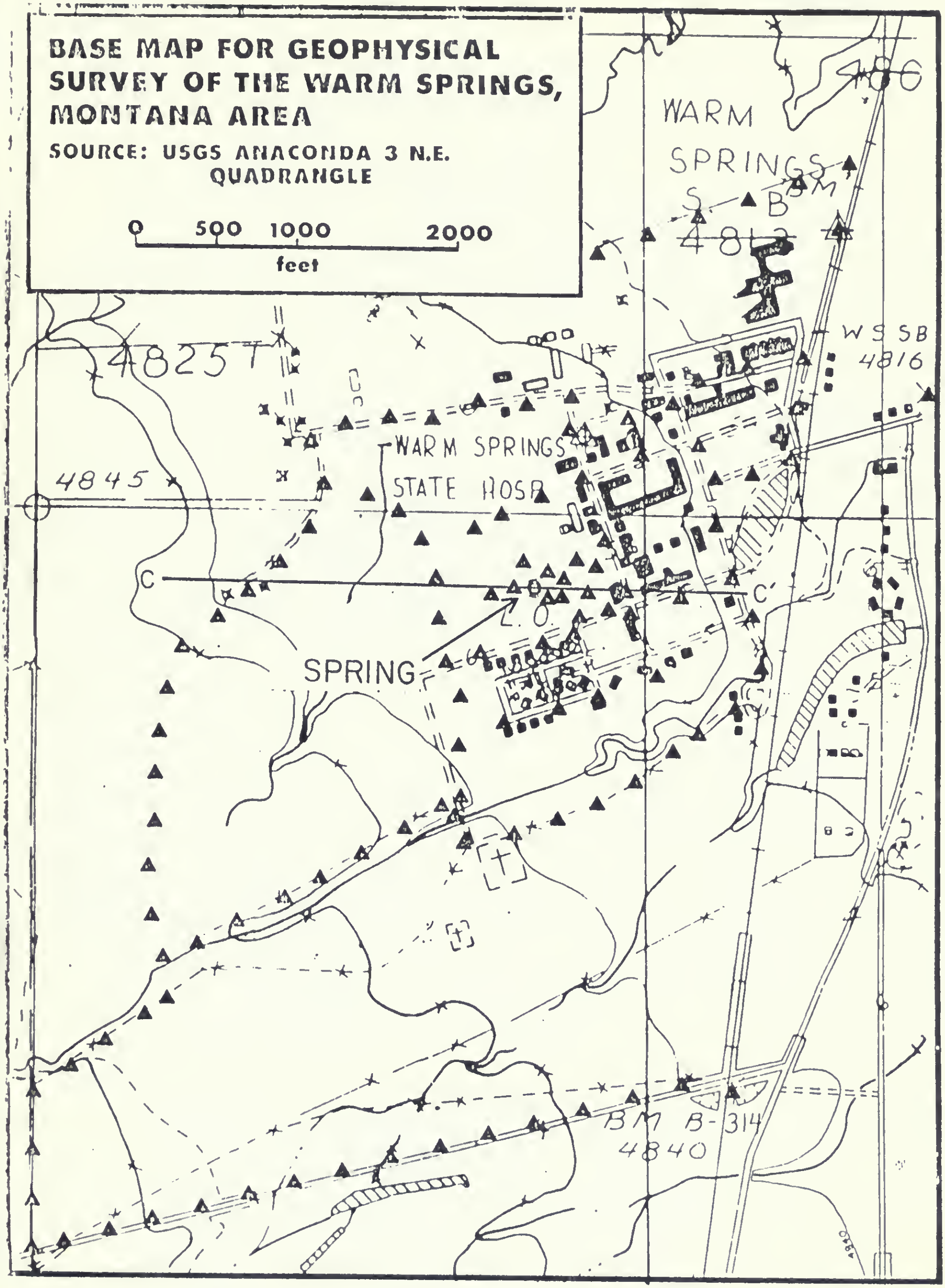

Figure 1. Map of the Warm Springs area showing gravity station locations and the location of cross section 2(c).

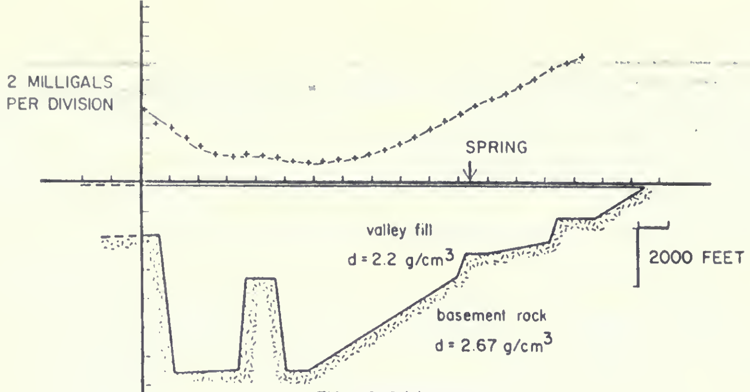

FIGURE 2 (a)

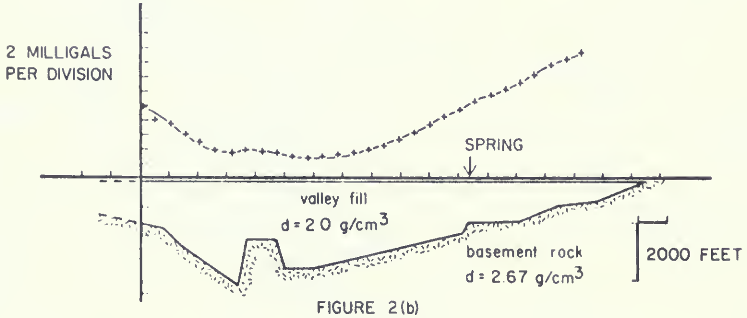

FIGURE 2 (b)

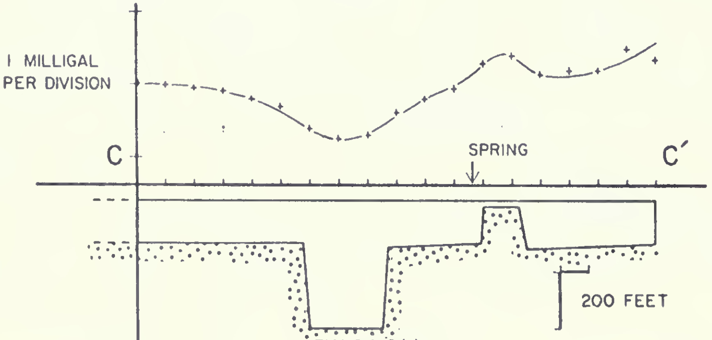

FIGURE 2 (c)

Figure 2. Figures 2(a) and (b) represent an east-west section across the Deer Lodge Valley showing two possible interpretations of the basement configuration resulting from two different valley-fill densities. Figure 2(c) shows the near-surface density distribution within the valley fill. Crosses indicate gravity data and the lines show the computer-calculated anomalies resulting from the assumed subsurface configuration.

VERTICAL EXAGGERATION - 2 TIMES

A GEOPHYSICAL INVESTIGATION OF THE WARM SPRINGS MONTANA AREA

The Deer Lodge Valley in southwestern Montana is the site of several moderate temperature thermal springs. Of these occurrences, the geothermal system on the grounds of the Warm Springs State Hospital shows considerable potential for the development of the energy source.

During the summer and fall of 1978 a geophysical survey was conducted in the vicinity of the State Hospital to gather information about the geothermal system. Possible targets for the survey included both basement and near-surface geologic features.

It is possible that the placement of the spring is the result of a structural feature in the rock underlying the valley fill. It was hoped that gravity data would reflect the presence of such a feature.

The arrival of water at the surface is accompanied by a deposition of material from solution. This suggests that deposition may also occur in the valley fill along the path of the ascending water. The increased density that would be expected with this deposition became one possible target of a detailed gravity survey in the vicinity of the spring.

It was also expected that the resistivity of the area would be affected by the geothermal water and thus allow mapping of its near-surface lateral extent.

LOCATION

Warm Springs is located in the southern part of the Deer Lodge Valley, west of the Clark Fork River. The Anaconda and Flint Creek mountain ranges create the western boundary of the valley and the eastern valley margin is apparent (Schofield, 1979). Valley fill consists of consolidated and unconsolidated Tertiary sediments and Quaternary alluvium (Konizeski, 1968).

SURVEY METHODS

Figure 1 is a map of the Warm Springs area showing the location of the gravity stations. Station spacing generally did not exceed three-hundred feet. Station elevations were taken from a level net and recorded to the nearest one-hundredth of a foot. Free air, latitude and Bouguer corrections were made upon the data but no terrain corrections were performed.

Resistivity data were gathered with an Eltran array of fifty meter "a" spacing. The survey was designed for profiling the area. Detailed surveys were performed in selected areas using and expanding Wenner array for which the "a" spacings varied from one meter to one hundred meters.

RESULTS

Figure 2(a), (b) and (c) are cross sections constructed utilizing a two-dimensional modeling program (Fleming, 1977). Figures 2(a) and (b) represent an east-west section passing through the spring, beginning approximately 22,000 feet west of the spring and ending approximately 11,000 feet to the east. The location of section 2(c) is shown on figure 1. In all profiles the crosses represent gravity data and the solid lines are the computer-calculated anomalies resulting from the assumed subsurface configuration.

Data for profiles 2(a) and (b) was taken from the U.S. Geological Survey Water Supply Paper 1862. In figure 2(a) a density of 2.2 g/cm^3 was chosen for the valley fill and 2.67 g/cm^3 for the basement material.

These values are in agreement with Burfiend (1967). A density log from a well drilled on the hospital grounds in November of 1979 shows that the average density of the valley fill may be only 2.0 g/cm^3. Figure 2(b) is a profile modeled to this density contrast. Figures 2(a) and (b), although generally similar in cross sectional shape, clearly show the variation of valley fill depth estimates resulting from the two density contrasts.

The small changes of slope that occur along the gravity profile near the east side of the valley are interpreted to be indicative of changes in the basement configuration. It is possible that these changes could be interpreted as expressions of normal faulting along the eastern edge of the valley.

Data for cross section 2(c) was taken from the residual gravity map shown in figure 3. The profile indicates a highly variable near-surface density distribution with the present-day springs occurring at a boundary between a gravity high and a gravity low.

Other notable features of the residual gravity map are the closed low near the upper-right corner of the map and the high southeast of the spring. The magnitude and area of the closed low probably indicate a small, near surface mass, the center of which may be 100 meters below the surface as calculated by the half-width method (Telford, et.al., 1976).

Applying the half-width method to the gravity high southeast of the spring it can be found that the center of mass may lie 195 meters below the surface. A possible interpretation of the high is that it is the expression of the deposition of materials in the near-surface gravels.

The following calculation is based upon the assumption that valley fill with a density in the range of 2.0 to 2.2 g/cm^3 may undergo a density

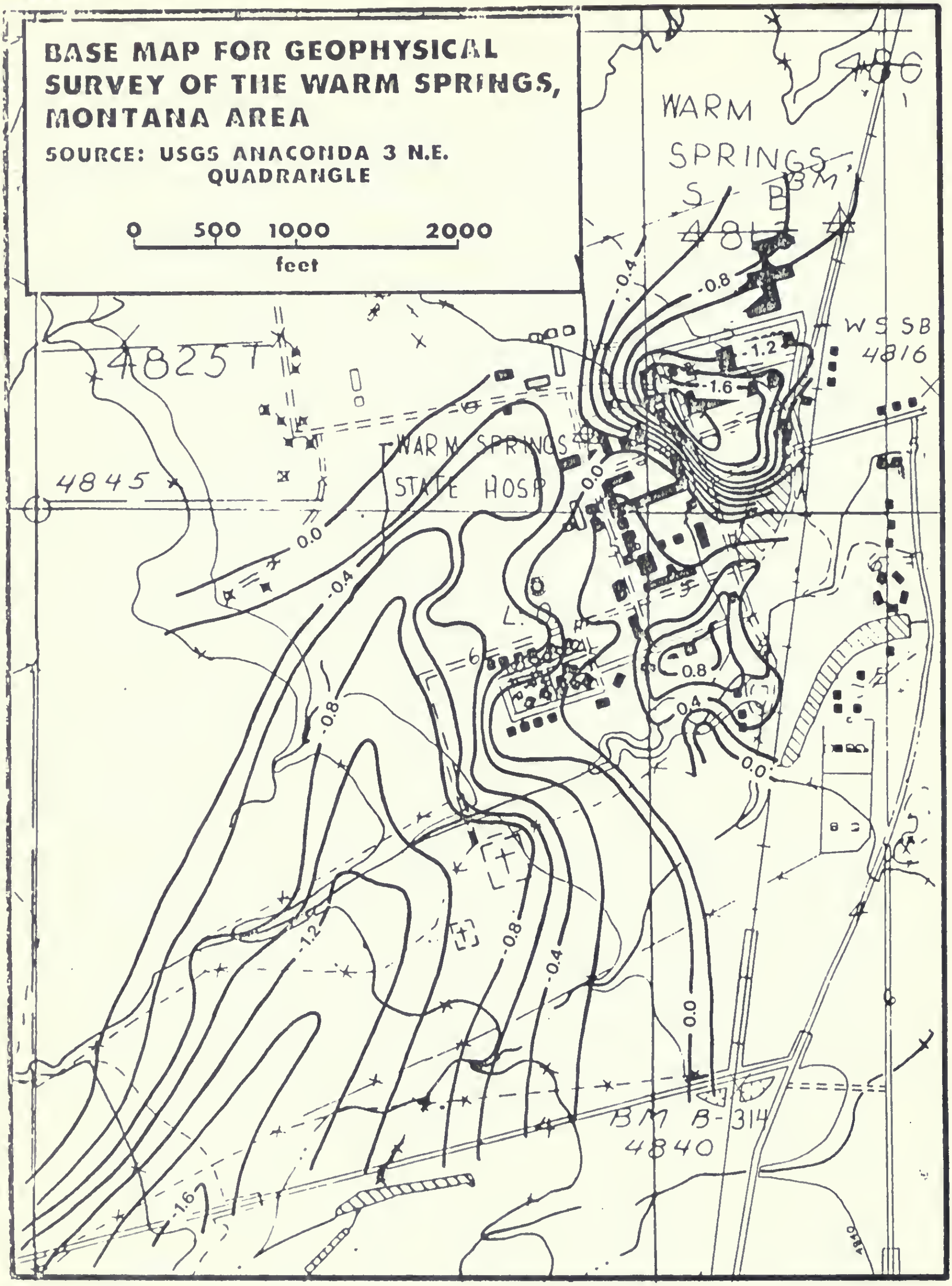

Figure 3. Residual gravity map of the Warm Springs area. 0.2 milligal contour interval.

increase of 0.3 to 0.4 g/cm^3 as the porosity decreases from 20 percent to 5 percent. Applying the increase of 0.4 g/cm^3 to a spherical mass of 150 meter radius and center of mass 195 meters below the surface the added attraction becomes:

$$g = \frac{4/3\ R^3 d}{z^2} \text{ X } G$$

where d = the density
$4/3\ R^3$ = the volume
z = depth to center of mass
G = gravitational constant $6.67 \times 10^{-8}\ \frac{\text{dynes-cm}^2}{g^2}$

$$g = 4/3\ \frac{(150m \times 100cm/m)^3 \times 0.4g/cm^3}{(195m \times 100cm/m)^2} \text{ X } G$$

g = 0.000992 gals or 0.992 milligals.

This value is in close agreement with the observed variations of gravity but would vary slightly with different densities or porosities.

Figure 4 is a contour map of the resistivity data taken in the vicinity of the spring. The contours show that the lowest resistivities surround the spring. The northeast trend of the contoured low might be attributed to the natural flow of the water as it reaches the surface. An alternate interpretation is that the northeast trend of the low indicates the position of the water entering the area. However, a free-flowing, warm water spring was encountered while excavation was being done for a basement approximately 800 feet east of the present spring and the occurrence of warm basements in houses southeast of the spring (Painter, 1978) indicates that the warm waters are present southeast of the spring. A distortion in the 10 ohm-meter contour also occurs southeast of the spring in the vicinity of the anomalous gravity high.

DISCUSSION OF RESULTS

Valley cross sections based upon an evaluation of gravity values for the Deer Lodge Valley show that the location of the warm spring seems

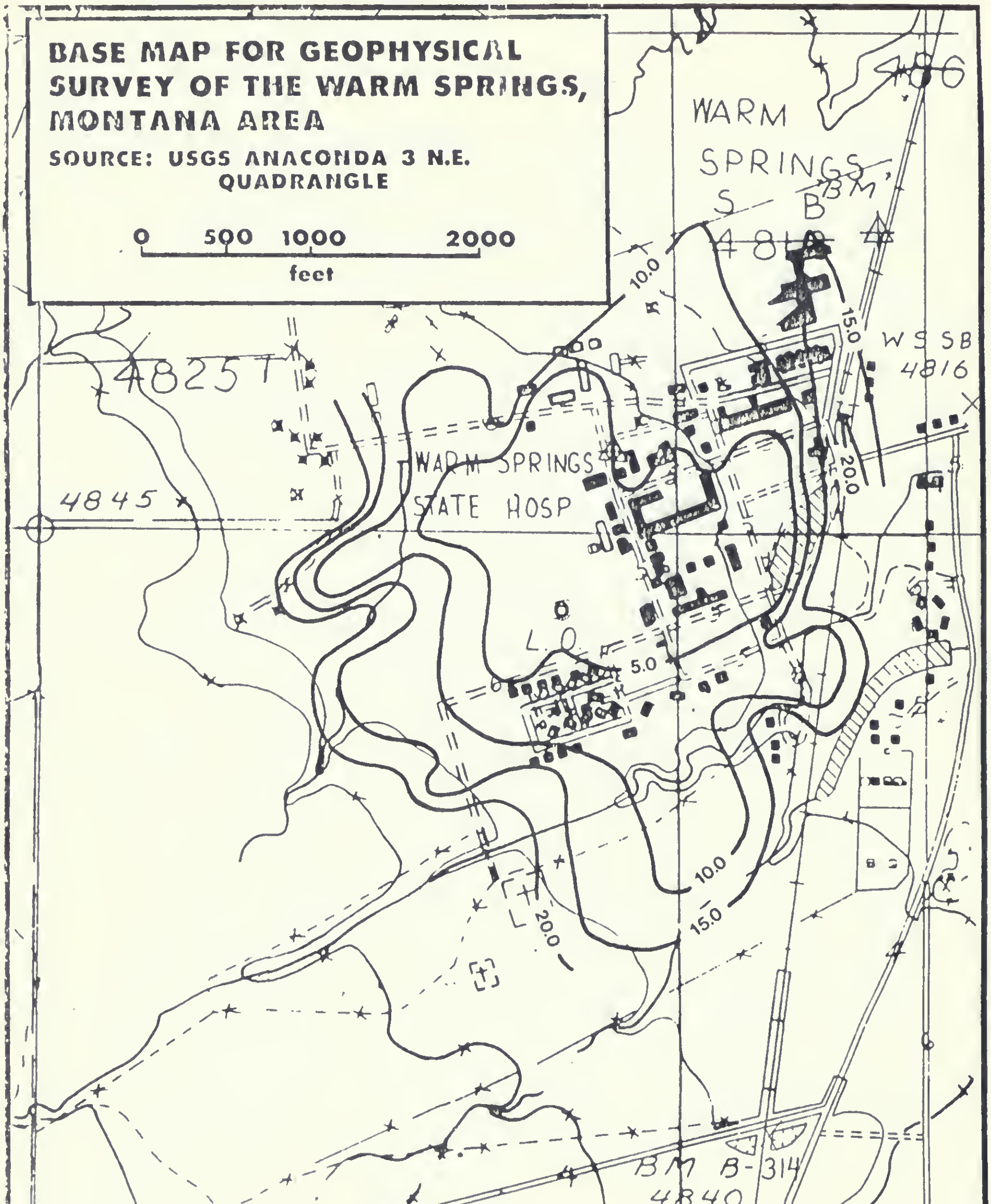

Figure 4. Resistivity contour map of the Warm Springs area based upon 50 meter Eltran dipole profiles. 5 ohm-meter contour interval.

to be associated with a change of basement configuration that could be interpreted as faulting along the east side of the valley.

The residual gravity map of the area adjacent to the spring shows a gravity low northeast of the spring and a slight gravity high to the east and southeast of the spring. No present explanation exists for the gravity low other than it is the expression of a near-surface body of low density material. The high, however, may be the expression of a slight density increase resulting from the deposition of materials from migrating geothermal waters as they cool near the surface. Such deposition may block the migrating water and control its dispersion through the gravels. Based upon this hypothesis, the gravity high may indicate that the waters reach the near surface somewhere to the southeast of the present springs.

The resistivity map of the area indicates that a near surface low resistivity zone surrounds the present day spring. The zone broadens to the north and northeast and extends into the region of the previously mentioned gravity low. The resistivity data may be representative of a system in which geothermal water reaches the near-surface and spreads laterally, the northeast elongation being due to the natural hydrologic gradient. Houses with warm basements and the discovery of a small spring indicate that the water may first reach the near-surface southeast of the present spring. A distortion in the 10 ohm-meter contour occurs in the vicinity of the anomalous gravity high.

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